

D-mixing and indirect CP violation measurements at LHCbSILVIA BORCHI¹*School of Physics and Astronomy,
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The LHCb experiment collected during run I the world's largest sample of charmed hadrons. This sample is used to search for CP violation in charm and for the measurements of D^0 mixing parameters. The measurement of the $D^0 - \bar{D}^0$ mixing parameters and the search for indirect CP -violation in two-body charm decays at LHCb experiment are presented.

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1 Introduction

The charm sector is a promising field to probe for the effects of physics beyond the Standard Model (SM). Flavour mixing in the charm sector is now well established [1]. In the SM [2, 3], the CP violation in charm transitions is expected to be small, with asymmetries up to few $\mathcal{O}(10^{-3})$, while it can be enhanced by contribution from New Physics [4].

The LHCb experiment is dedicated to the study of b and c flavour physics. The abundance of charm particles produced in LHC offers an unprecedented opportunity for high precision measurements in the charm sector, including measurements of CP violation and $D^0 - \bar{D}^0$ mixing.

The results of search for indirect CP violation and the measurements of the mixing parameters in two body hadronic D^0 charm decays are presented here.

2 Mixing and CP violation with $D^0 \rightarrow K^+ \pi^-$ decays

The flavour mixing occurs because the mass eigenstates ($|D_{1,2}\rangle$) are linear combinations of the flavour eigenstates $|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$, with complex coefficients p and q which satisfy $|p|^2 + |q|^2 = 1$. The mixing parameters are defined as $x \equiv (m_1 - m_2)/\Gamma$ and $y \equiv (\Gamma_1 - \Gamma_2)/(2\Gamma)$, where m_1, m_2, Γ_1 and Γ_2 are the masses and the decay widths for D_1 and D_2 , respectively, and $\Gamma = (\Gamma_1 + \Gamma_2)/2$. The phase convention is chosen such that $CP|D^0\rangle = -|\bar{D}^0\rangle$.

The first evidence of $D^0 - \bar{D}^0$ oscillation was reported in 2007 by BaBar [5] and Belle [6]. Now, the mixing in the charm sector is well established with the first observation by a single measurement with greater than 5 standard deviation significance at the LHCb experiment [7], confirmed by CDF [8] and Belle [9].

At the LHCb experiment, the charm mixing parameters are determined by the decay-time-dependent ratio of $D^0 \rightarrow K^+ \pi^-$ (called wrong sign, WS) to $D^0 \rightarrow K^- \pi^+$ (called right sign, RS) decay rates. The RS decay rate is dominated by Cabibbo favoured (CF) amplitude. The WS rate arises from the interfering amplitudes of the doubly Cabibbo-suppressed decay (DCS) and the CF decay following $D^0 - \bar{D}^0$ oscillation. Assuming no CP violation and small mixing parameters ($|x|$ and $|y| \ll 1$), this ratio is:

$$R(t) \approx R_D + \sqrt{R_D} y' \frac{t}{\tau} + \frac{x'^2 + y^2}{4} \left(\frac{t}{\tau} \right)^2$$

where $x' = x \cos \delta + y \sin \delta$, $y' = y \cos \delta - x \sin \delta$, R_D is the ratio of suppressed-to-favoured decay rates, δ is the strong phase difference between the DCS decays and the CF decays ($\mathcal{A}(D^0 \rightarrow K^+ \pi^-) / \mathcal{A}(D^0 \rightarrow K^- \pi^+) = -\sqrt{R_D} e^{-i\delta}$).

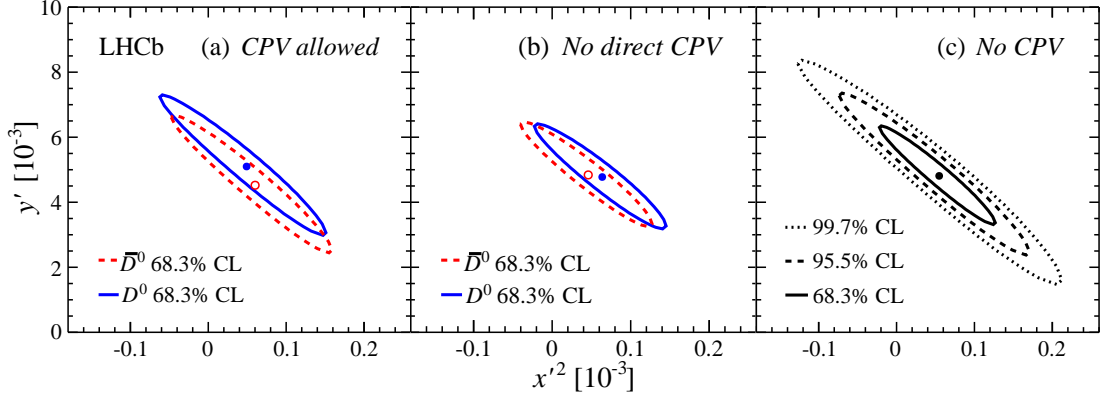


Figure 1: Two-dimensional confidence regions in the (x'^2, y') plane obtained a) without any restriction on CP violation, b) assuming no direct CP violation and c) assuming CP conservation. The solid (dashed) curves in a) and b) indicate the contours of the mixing parameters associated with D^0 (\bar{D}^0) decays. The solid, dashed and dotted curves in c) indicate the contours of CP -averaged mixing parameters at 68.3%, 95.5% and 99.7% C.L.. The best-fit value is shown with a point [10].

One can search for CP violation in the charm sector by comparing the time-dependent ratios evaluated separately for the two flavours (D^0 and \bar{D}^0). A difference in the R_D parameter between D^0 and \bar{D}^0 would be a sign of direct CP violation. While a difference in x'^2 and y' parameters would imply an indirect CP violation contribution ($|q/p| \neq 1$ or $\phi = \arg(q/p) \neq 0$). The data are fit considering three scenarios: 1) assuming CP conservation 2) allowing only indirect CP contribution; 2) allowing both direct and indirect CP contributions.

The full data sample with a total integrated luminosity of 3 fb^{-1} is used to perform these measurements. The analysis is performed on $D^{*\pm} \rightarrow D^0 \pi^\pm$ decays to allow the determination of the flavour of the neutral D meson at production.

In the scenario 1) the mixing parameters are measured to be $R_D = (3.568 \pm 0.058 \pm 0.033) \cdot 10^{-3}$, $y' = (4.8 \pm 0.8 \pm 0.5) \cdot 10^{-3}$ and $x'^2 = (5.5 \pm 4.2 \pm 2.6) \cdot 10^{-5}$ where the first uncertainty is statistical and the second systematic. In the scenario 2) and 3), the magnitude of $|q/p|$ is constructed. The magnitude of q/p is determined to be $0.75 < |q/p| < 1.24$ and $0.67 < |q/p| < 1.52$ at 68.3% and 95.5% C.L., respectively [10]. The results of the mixing parameters measurements and of the confidence regions are shown in Fig. 1 for the three scenarios. They are compatible with CP conservation and provide the most stringent bounds on the parameter $|q/p|$ from a single experiment.

3 Indirect CP violation in 2-body D^0 decays to CP eigenstates

A measurement of the indirect CP violation in D^0 mixing can be performed in the study of two-body hadronic charm decays to CP eigenstates ($D^0 \rightarrow K^+ K^-$ or $D^0 \rightarrow \pi^+ \pi^-$). It can be evaluated by the asymmetry in the effective lifetimes (τ) of flavour-tagged decays and it can be expressed by the following equation with the assumption of negligible direct CP -violation contribution:

$$A_\Gamma = \frac{\tau(\bar{D}^0 \rightarrow f) - \tau(D^0 \rightarrow f)}{\tau(\bar{D}^0 \rightarrow f) + \tau(D^0 \rightarrow f)} \approx \frac{1}{2} A_m y \cos \phi - x \sin \phi$$

where A_m is defined by $|q/p|^{\pm 2} \approx 1 \pm A_m$. A measurement of A_Γ differing significantly from zero is a manifestation of indirect CP violation as it requires a non-zero value for A_m or ϕ .

The measurement of A_Γ at LHCb is performed using 1 fb^{-1} of data from a sample of pp collisions at a centre-of-mass energy of 7 TeV collected in 2011. The flavour at production is again determined using neutral D mesons from $D^{*\pm} \rightarrow D^0 \pi^\pm$ decays. The main selection is applied at the trigger level on the momentum, PID and impact parameter (IP) of the D^0 daughters. The trigger event selection causes a bias of the proper-time distribution. Thus, an acceptance correction is needed for the evaluation of the effective lifetime. The acceptance is determined using a data driven method, the so-called swimming algorithm [11, 12].

The fit to determine the effective lifetime is performed independently for each flavour tag and each decay mode. The signal yield are extracted from simultaneous unbinned likelihood fits of the D^0 invariant mass and of the difference between D^* and D^0 masses, Δm , to distinguish the different background contributions. Charm mesons produced in b -hadron decays, secondary charm, have larger impact parameter with respect to the primary vertex than the prompt candidates as a secondary D does not usually point back to the primary vertex. This additional background is subtracted in a simultaneous fit of the proper-time and $\ln(\chi_{IP}^2)$ distributions. The χ_{IP}^2 is defined as the difference in χ^2 of a given primary interaction vertex reconstructed with and without the considered particle. Fig. 2 shows an example of the proper-time projection for $D^0 \rightarrow K^+ K^-$ and $D^0 \rightarrow \pi^+ \pi^-$ decays for one data set.

The analysis method is validated on a control sample of CF $D^0 \rightarrow K^- \pi^+$ decays, where the lifetime asymmetry is determined to be consistent with zero in accordance with the expectation. The resulting values of A_Γ for the two final states [13] are:

$$\begin{aligned} A_\Gamma^{KK} &= (-0.35 \pm 0.62 \pm 0.12) \cdot 10^{-3} \\ A_\Gamma^{\pi\pi} &= (0.33 \pm 1.06 \pm 0.14) \cdot 10^{-3} \end{aligned}$$

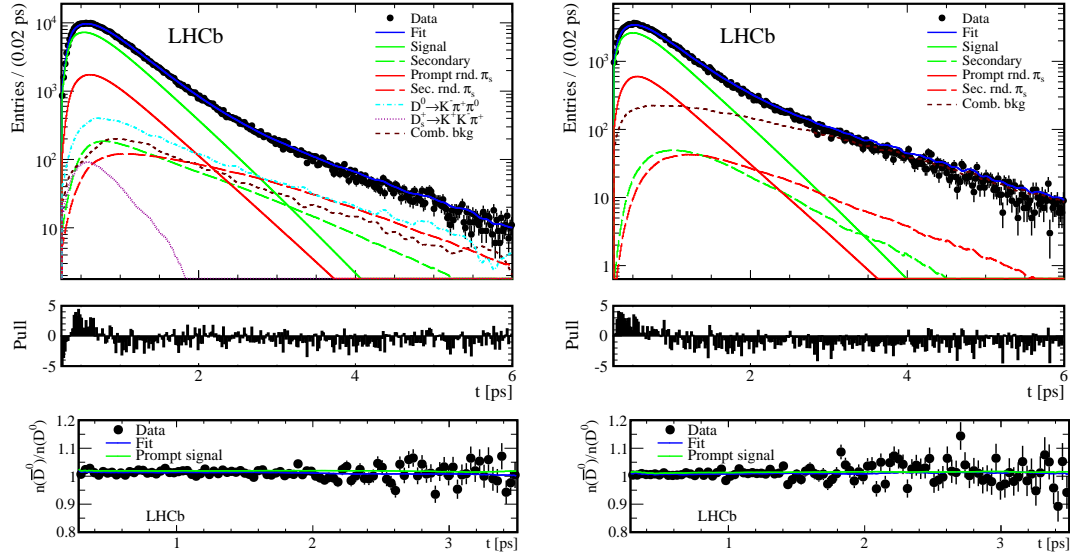


Figure 2: Lifetime fit projection of $\bar{D}^0 \rightarrow K^+K^-$ decays (on the top left) and of $\bar{D}^0 \rightarrow \pi^+\pi^-$ decays (on top right) and corresponding pull plot, for one data set. The ratio of \bar{D}^0 to D^0 data and fit model for decays to KK (on the left bottom) and $\pi^+\pi^-$ (on the right bottom) for all data, respectively [13].

where the first uncertainty is statistical and the second systematic. Both results are consistent with zero, showing no evidence for indirect CP violation. They are consistent with and more precise than previous determinations from other experiments [1]. Amongst the several sources of systematics considered, the main ones are due to the decay-time acceptance correction and due to the background description.

4 Conclusion

The mixing in charm sector is now well established, while searches for indirect CP violation yield results consistent with CP conservation. Further measurements are ongoing at LHCb using the data set collected during Run I and others will follow with the upcoming Run 2, allowing to explore the charm sector with unprecedented precisions. Later, the LHCb Upgrade is expected to collect 50 fb^{-1} of integrated luminosity, allowing to reach precisions down to $0.5 \cdot 10^{-3}$ for A_F and $\mathcal{O}(10^{-5}, 10^{-4})$ for (x'^2, y') .

References

- [1] Heavy Flavor Averaging Group, Y. Amhis et al., arXiv:1207.1158 and online update at <http://www.slac.stanford.edu/xorg/hfag>
- [2] M. Golden and B. Grinstein, Phys. Lett. B **222**, 501 (1989).
- [3] M. Bobrowski, A. Lenz, J. Riedl and J. Rohrwild, JHEP **1003** 009 (2010).
- [4] Y. Grossman, A. L. Kagan and Y. Nir, Phys. Rev. D **75**, 036008 (2007).
- [5] BaBar Collaboration, B. Aubert et al., Phys. Rev. D **98** 211802 (2007).
- [6] Belle Collaboration, M. Staric et al., Phys. Rev. D **98** 211803 (2007).
- [7] LHCb Collaboration, R. Aaij et al., Phys. Rev. Lett. **110** 101802 (2013).
- [8] CDF Collaboration, T. Aaltonen et al., Phys. Rev. Lett. **111** 231802 (2013).
- [9] Belle Collaboration, B. R. Ko et al., Phys. Rev. Lett. **112** 111801 (2014).
- [10] LHCb Collaboration, R. Aaij et al.; Phys. Rev. Lett. **111** 251801 (2013).
- [11] LHCb Collaboration, R. Aaij et al., Phys. Lett. B **707** 349356, (2012).
- [12] LHCb Collaboration, R. Aaij et al., JHEP **04** 129, (2012).
- [13] LHCb Collaboration, R. Aaij et al., Phys. Rev. Lett. **112**, 041801 (2014)